Capacity of DECT Wireless Local Loop System in Multi-Cell Environment

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Abstract- Wireless Local Loop (WLL) provides reliable, flexible, and economical access to local telephone service using radio technology in the place of traditional copper wireline. A variety of wireless technologies are currently available for the local loop. Digital Enhanced Cordless Telecommunications (DECT) is one of these. Several DECT based WLL products from different vendors have been commercially deployed, or are under trial worldwide. Many of these systems have been installed in rural areas in a single cell-configuration, but many also in built-up areas in multi-cell configurations. The capacity of these multi-cell systems is not well known, due to the variable number of channels available at a given instant in time. In this paper we present the results of thorough simulation of a DECT based WLL system in a multi-cell environment.

1. Introduction

Wireless communication networks have come into their own within the last decade. This is seen in the multitude wireless systems commercially available. To understand why telephone service providers throughout the world are turning more and more to wireless solutions to provide service to their customers, one must look at the alternative, wireline networks. Until recently, wireline was the only viable solution available. Wireline networks transport voice that has been converted into a data stream, either analog or digital, using some form of wired media, typically copper wire or fiber optics. Deployment of wireline networks to large service areas is usually very expensive.

In many regions across the world a relatively small percentage of homes are wired for telephony services. Local or national governments see the sparse availability of telephony services as a constraint on economic development. Service providers, meanwhile, see untapped revenue potential in unwired regions. Increasingly service providers are turning to wireless technology to quickly and permanently implement cost-effective local loop. Wireless Local Loop (WLL) offers an additional tool that can simplify the task of providing telephony services throughout a region. Service providers can also look to a combination of the wireless and land-line alternatives to best serve a particular region.

While there are several advantages to wireless systems, the basic nature of radio communications results in some drawbacks. Interference reduces the quality and number of usable radio channels. In addition, most wireless systems require line of sight path between the transmitter and the receiver, meaning that there are no obstructions between the transmit and receive antenna. Notwithstanding, the development of new and better wireless technologies continues, and today wireless systems can provide excellent service for a variety of applications. DECT is one of the major radio technologies developed for WLL. This technology was originally developed for wireless private branch exchange and low mobility in Europe to replace the Cordless Telephone-2 standard. However, it was eventually enhanced in Europe and the United States to address WLL aspects as well. An American standard similar to DECT is called Personal Wireless Telecommunications (PWT) for unlicensed use, and PWT-E for licensed use in the PCS band.

An important feature of DECT is its dynamic channel allocation scheme. This feature mitigates the effects of interference and negates the need to do frequency planning. The dynamic channel allocation scheme works as follows: All channels are initially available in every sector. As calls are placed, a channel is available for reuse based on its interference level. The interference depends on the specific radio propagation corresponding to many users on the same channel in different locations, and varies as calls are placed and terminated. The capacity of a DECT system with dynamic channel allocation has not been investigated in the context of WLL applications. Furthermore there is little information on coverage and capacity. This paper addresses both these issues by providing the results of a set of detailed computer simulations conducted at Bell Labs. We present capacity simulation results of a DECT based WLL system in different types of environments with different number of sectors per cell. These results demonstrate the capability of DECT technology and will help any service provider planning DECT based local loop.

2. System Configuration and Characteristics

We define WLL services as fixed wireless services intended to provide primary access to the telephone network that is, wireless services supporting subscribers in fixed and known locations. The fixed subscriber communicates with a base station using a radio technology. The base station is connected to a public switched telephone network (PSTN). Figure 1 shows a typical illustration of such a system.

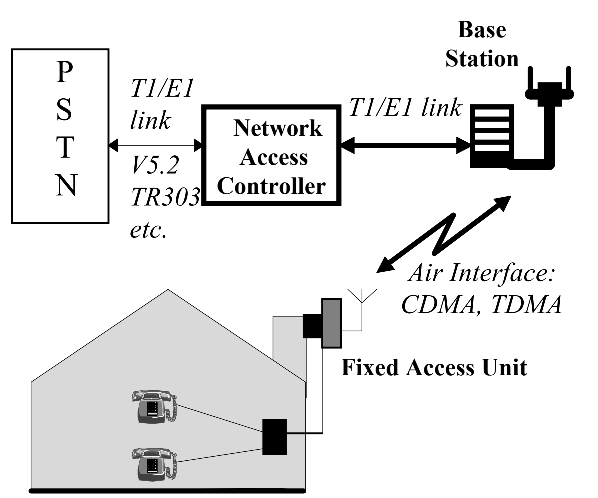

Figure 1: Typical WLL system configuration.

Several radio technologies are being used in the air-interface of WLL systems including IS-95, IS-136, DECT, PHS, PACS, and some proprietary CDMA and TDMA technologies. Herein we shall only concentrate in the use of the DECT technology as an air-interface.

3. DECT Main Features

The DECT air-interface technology is based on time division multiple access (TDMA) and time division duplex (TDD) on multiple RF carriers. Ten carriers are provided in the frequency band 1880 to 1900 MHz (other bands are also being considered to meet future demand, such as 1910 to 1930 MHz etc.) On each carrier the TDMA structure defines 24 time slots (12 for each direction) in a 10 ms frame, where each time slot may be used to transmit one self contained packet of data. One of the most important features of DECT is the use of Dynamic Channel Selection (DCS) which allows different systems and system operators to utilize the same group of available channels without prior distribution of channels to specific services or bases stations.

Table 1 summarizes the DECT system characteristics that pertain to the radio link.

Table 1. DECT Radio Link Characteristics.

Access Technology	TDMA/FDMA	
Duplex	Time Division	
Frequency Band	1880-1900 MHz	1910-1930 MHz
RF Carrier Spacing	1.728 MHz	
Number of RF Carriers	10	
TDMA Frame Length	10 ms	
Time Slots Per Frame	24	12 per link
Speech Codec	ADPCM	32 kbps
Transmit Power	24 dBm	(250mW) fixed
Base Station Ant. Gain	16 dBi	typical for WLL
Sub. Ant. Gain	10 dBi	typical for WLL
Noise Bandwidth	2 MHz	
Sub & BS Noise Figure	8 dB	typical for WLL
Modulation	GMSK	B_t=0.5
Required Eb/No (AWGN)	9 dB	BER=10^{-3} [1]
Adjacent Carrier Power	-43 dB	below main carrier [2]

4. Simulation Scenarios and Assumptions

In our simulation the following scenarios were considered:

- <u>Scenario 1</u>: <u>1-sector plan</u>: In this plan the system is assumed to be not sectored (one sector per cell, i.e. omni cell) and the environment is an <u>open rural area</u>. The base stations are laid out on a 5 by 5 grid of cells in a square configuration with one base station per cell. The cell size, as measured by one side of the square cell is 16 km which gives a maximum radius of 11.2 km.
- <u>Scenario 2</u>: <u>4-sector plan:</u> In this plan we assume that a sectored system with 4 sectors per cell is deployed. A <u>suburban environment</u> is considered for this scenario. As in Scenario 1, the base stations are

laid out on a 5 by 5 grid of cells in a square configuration with four base stations per cell which corresponds to one base station per sector. The cell size, as measured by one side of the square cell is 4 km which gives a maximum radius of 2.8 km.

- Scenario 3: 6-sector plan: In this plan we assume that a sectored system with 6 sectors per cell is deployed. An urban environment is considered for this scenario. In contrast to Scenario 1 and 2, in this scenario, the base stations are laid out on a grid of 20 cells in a hexagonal configuration. The cell radius, as measured by one side of the hexagon is 1 km. Figure 2 shows the cell layout for the 4 and 6 sector plans (Scenario 2 and 3 respectively).

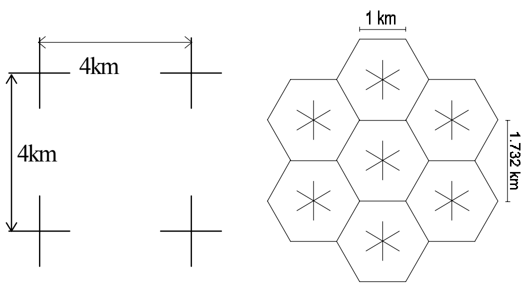

Figure 2. The 4 and 6-sector plans.

In our simulation the following assumptions and systems parameters were considered:

In contrast to mobile radio systems, the subscriber unit in most WLL systems use a directional antenna. To determine the effect of using more directive antennas at the subscriber unit, antennas with different half power beamwidths (90, 60, and 30 degrees) were considered in each of the three Scenarios.

An omni-directional antenna at the base station is considered in Scenario 1, and directional antennas with half power beamwidths of 90 and 60 degrees are considered in Scenarios 2 and 3 respectively.

The COST-231-Hata model [3] is used to estimate the propagation path loss in urban, suburban and rural environments. In each of the three Scenarios the base station antenna height is 30 m and the subscriber antenna height is 7.5 m. Shadow fading with 5 dB standard deviation is also considered.

The call inter-arrival time and holding time are exponentially distributed. A level of traffic in Erlangs is specified per sector, and the blocking rate is then found from the simulation.

DECT systems have 10 RF carriers, and each carrier has 12 time slots, for a total of 120 DECT channels. All 120 channels are available in each sector. There are enough radios at each cell such that all 120 channels may be used simultaneously in each sector.

Channel assignment on both the uplink and downlink is accomplished by finding the least interfered channel (LIC) and then testing the signal to interference ratio (SIR) [4,5]. For uplink channel assignment, the LIC is found at the base. For the downlink channel assignment, the LIC channel is found at the user. If the SIR is greater than the call setup SIR then the user's call is accepted, and if not then the call is dropped.

Channel reassignments can occur during the course of a call. Reassignment occurs when a new user enters the system generating interference to existing users on the same channel. If the SIR falls below the reassignment SIR then a new channel is found. During the course of a call, a call is held even if the SIR falls below the reassignment SIR threshold and no better channel can be found.

The fade margin is defined as the difference between the Eb/No required in an additive white Gaussian noise (AWGN) channel and the Eb/No required in a fading channel. The fade margin is an input parameter in the simulation. We estimate this parameter in following discussion. Most WLL DECT based systems use Gaussian minimum shift keying (GMSK) without forward error correction and two branch space diversity at the base station. Since DECT is time division duplexed, the best antenna for transmitting is also considered to be the best antenna for receiving. Diversity can be effective provided that the antenna spacing is large enough. Therefore, we can say that diversity is achieved on both the reverse and forward links. Figure 3 shows the bit error rate (BER) performance of GMSK in an AWGN and fading channels. From this figure we can say that the Eb/No required to achieve a BER of 10^{-3} in an AWGN channel is about 8 dB. Since the DECT receiver uses non-coherent detection, there is a penalty of about 1 dB. Thus Eb/No required is about 9 dB for a DECT receiver in an AWGN channel. Figure 3 also shows that with selection diversity in a Rician channel with K factor equals 3 dB, the required Eb/No to achieve a BER of 10^{-3} is 12 dB. For a DECT receiver using non-coherent detection, there is a 3 dB penalty in fading channel. Thus the required Eb/No is 15 dB. The fade margin in this case is 6 dB and such a number is considered in our simulation. This 6 dB fade margin represents the worst case since the fading in a fixed wireless local loop channel is expected to be a Rician distributed with a K factor greater than 3 dB.

In the simulation the reassignment SIR (including the fade margin) is considered to be 15 dB and the call setup SIR (including the fade margin) is considered to be 20 dB.

Finally in our simulation the base stations are assumed to be time synchronized as it is the case in the DECT standard.

5. Simulation Results

A DECT based WLL system was simulated as described in Section 4. Figures 4, 5, and 6 show the Erlang traffic capacity per sector as a function of the probability of blocking for the 1-sector, 4-sector, and 6-sector plans respectively. Tables 2 and 3 present the traffic capacity in Erlang per cell at 1% and 0.1% blocking probability respectively.

Table 2. Erlang traffic per cell for each plan at 1 % blocking.

	Subscriber Antenna Beamwidth		
Plan	90 deg.	60 deg.	30 deg.
1-Sector	21	29	46
4-Sector	52	69	93
6-Sector	94	110	122

Table 3. Erlang traffic per cell for each plan at 0 .1 % blocking.

	Subscriber Antenna Beamwidth		
Plan	90 deg.	60 deg.	30 deg.
1-Sector	16	22	34
4-Sector	40	53	76
6-Sector	52	91	103

For Scenario 1, the 1-sector plan, simulation results show that, depending on the subscriber antenna, between 21 and 46 Erlangs per cell may be carried at 1% blocking. For 21 Erlangs of traffic, the Erlang-B formula estimates the number of effective radio channels to be approximately 30. Out of a possible 120 channels this corresponds to a frequency reuse of 120 divided by 30, or 4.

For Scenario 2, the 4-sector plan, simulation results show that, depending on the subscriber antenna, between 52 and 93 Erlangs per cell may be carried at 1% blocking. For 52 Erlangs of traffic, the Erlang-B formula estimates the number of effective radio channels to be 65. Out of a possible 120 channels this corresponds to a frequency reuse of 120 divided by 65, or about 2.

For Scenario 3, the 6-sector plan, simulation results show that, depending on the subscriber antenna, between 94 and 122 Erlangs per cell may be carried at 1% blocking. For 94 Erlangs of traffic, the Erlang-B formula estimates the number of effective radio channels to be 110. Out of a possible 120 channels this corresponds to a frequency reuse of 120 divided by 110, or approximately 1.

By decreasing the subscriber antenna beamwidth, the interference received and transmitted is reduced. As observed from Figures 4 to 6, and Tables 2 and 3, the simulation results show significant capacity gains by reducing the beamwidth from 90 to 30 degrees.

Increasing the number of sectors also increases the capacity per cell by reducing the interference. This is observed in the simulation results as well. The 1, 4, and 6 sector plans can not be compared directly as each plan considers a different environment - open, suburban, and urban respectively, and uses the appropriate propagation model for the given environment. Still, at 1% blocking and 30 degree subscriber antenna, the 4-sector plan has roughly 2 times the capacity of the 1-sector plan, and the 6-sector plan has roughly 3 times the capacity of the 1-sector plan.

We also investigated the effect of varying the cell radius. An increase in the cell radius results in an increase of the probability of blocking for fixed Erlang traffic or a reduction in the Erlang traffic for fixed blocking probability. Figure 7 shows the probability of blocking versus cell radius for the three plans. For each plan the subscriber antenna was kept fixed to 30 degrees, and the Erlang traffic per sector was fixed to 40, 22, and 20 for 1 sector, 4 sector, and 6 sector plans respectively. As indicated in the figure, as the cell radius increases the blocking percentage also increases. This is mainly due to the fact that as the cell radius is made larger more subscribers will receive barely enough signal. In a heavily loaded system these subscribers are susceptible to interference and may be blocked.

6. Conclusions

We demonstrated the capability of a DECT based WLL system for rural, suburban, and urban multi-cell environments. Simulation results indicate for omni-sector deployment 21 to 46 Erlangs of traffic per cell, for 4-sector suburban deployment 53 to 93 Erlangs of traffic per cell, and for 6-sector urban deployment 94 to 122 Erlangs of traffic per cell, may be carried at 1% blocking for subscriber antenna beamwidths from 30 to 90 degrees. By decreasing the subscriber antenna beamwidth significant capacity gain may be obtained. We also observed that increasing the cell radius decreases the capacity for a fixed blocking percentage or increases the blocking probability for fixed traffic.

References

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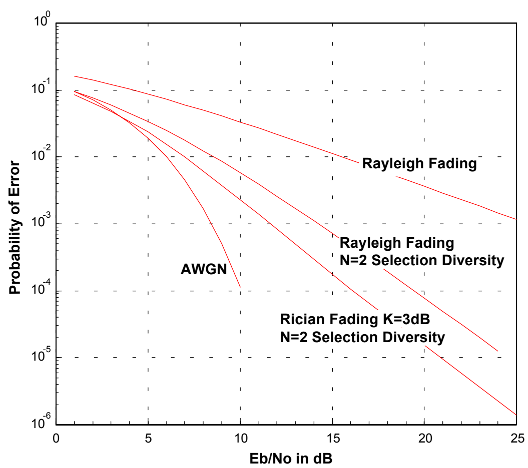

Figure 3. Bit error rate performance of GMSK in fading channels.

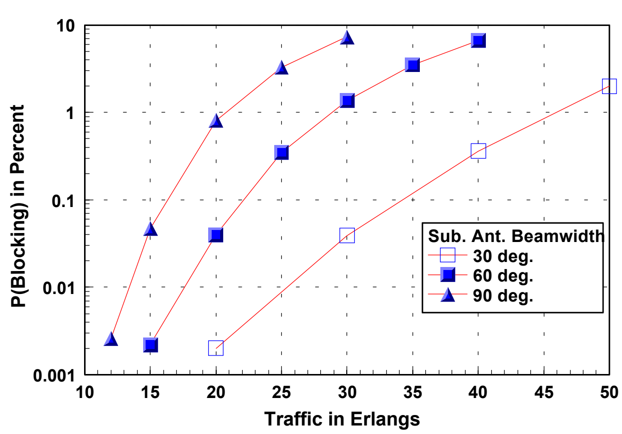

Figure 4. Erlang traffic per sector vs. blocking probability for 1-sector plan in rural environment with 11.2 km range (cell radius).

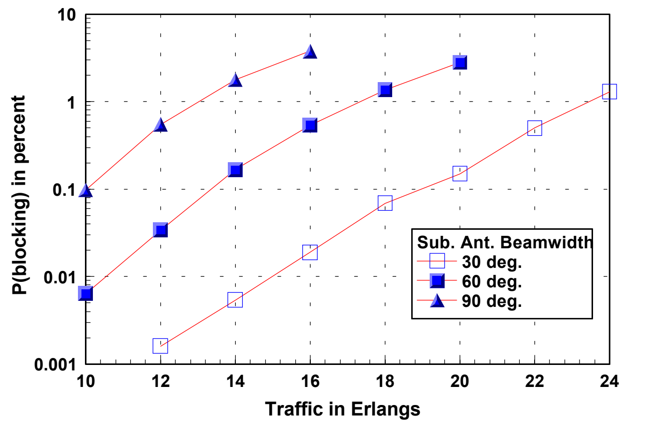

Figure 5. Erlang traffic per sector vs. blocking probability for 4-sector plan in suburban environment with 2.8 km range.

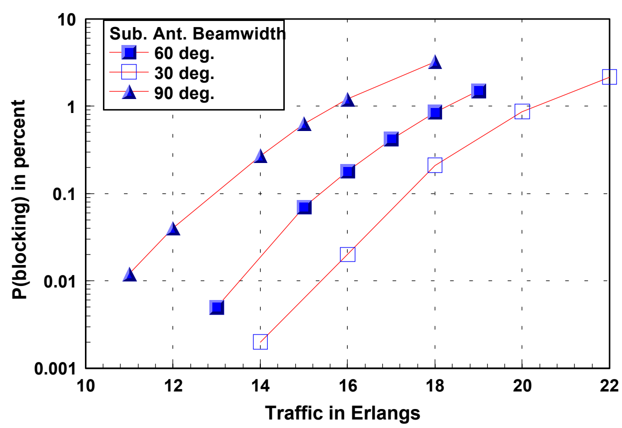

Figure 6. Erlang traffic per sector vs. blocking probability for 6-sector plan in urban environment with 1 km range.

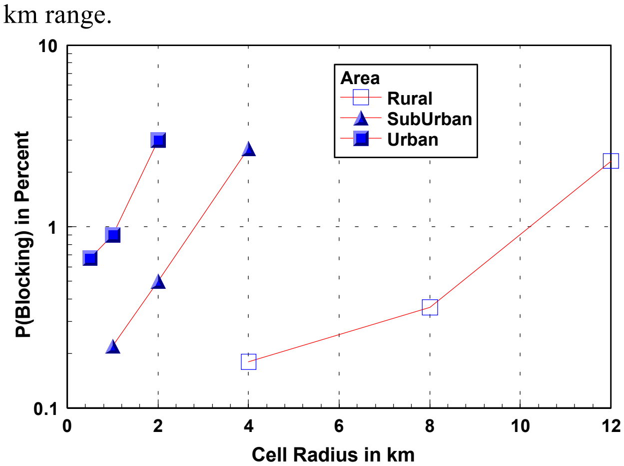

Figure 7. Blocking probability vs. range for 1-sector (rural), 4-sector (suburban) and 6-sector (urban) plans assuming Erlang Traffic of 40, 22, and 20 per sector.